# Radio Frequency Interference Effects of Continuous Wave Signals on Telemetry Data: Part II

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*In a previous report (DSN Progress Report 42-40), the results of the first series of radio frequency interference tests and an empirical telemetry bit SNR degradation model derived for a fixed telemetry data rate and a fixed telemetry data power were presented.*

*In this report, Part II, the results of a second series of radio frequency interference tests and the derived telemetry bit SNR degradation model, which includes the telemetry data rate and the telemetry data power as independent variables for characterizing the continuous wave interference effects on telemetry data, are presented. This generalized telemetry bit SNR degradation model has been implemented in the second version of the Deep Space Interference Prediction software.*

## I. Introduction

As part of an ongoing effort to investigate radio frequency interference (RFI) effects on Deep Space Network (DSN) spacecraft telecommunication signals, a series of RFI tests was formulated and conducted with standard Deep Space Station (DSS) equipment to investigate continuous wave (CW) interference effects on telemetry data in 1976. In analyzing the effects, the CW interference was treated as an extraneous noise. Empirical telemetry bit signal-to-noise ratio (SNR) degradation and drop-lock models were then developed based on test data and certain physical characteristics of the telemetry data processing system. These tests and resulting models, which were described in a previous report (Ref. 1), however, were strictly for a telemetry data rate of 2000 bps and a telemetry data power of about -140.5 dBm. To further understand the CW interference effect on telemetry data as a function of the telemetry data rate and the telemetry data power, a second series of RFI tests was conducted at the Goldstone Deep Space Station (DSS 11). This report describes these tests and the new telemetry bit SNR degradation model derived.

## II. Telemetry Interference Test

### A. Test Objectives

The test objectives were (1) to characterize the telemetry bit SNR degradation as a function of the telemetry data rate and the telemetry data power in the presence of a CW interfering signal, (2) to integrate the results into the previously developed telemetry bit SNR degradation model (Ref. 1) to form a generalized telemetry bit SNR degradation model, and (3) to investigate the CW interference effect on the high-order telemetry subcarrier harmonics.

## B. Test Configuration

A block diagram of the test configuration is shown in Fig. 1. The carrier tracking and telemetry data processing system is the standard DSS equipment. The Simulation Conversion Assembly (SCA) was used to generate two binary data streams; each data stream bi-phase-modulated a squarewave subcarrier. The two composite (data plus subcarrier) signals are then mixed and used to phase-modulate a continuous wave carrier. Operations support software was used in the Telemetry and Command Processor (TCP) to provide the telemetry data SNR statistics.

The desired downlink signal used for the test was a typical Viking spacecraft dual-subcarrier downlink signal. However, only the effects on the high-rate subcarrier were investigated. Table 1 summarizes the exact desired downlink signal configuration.

## C. Test Cases

Seventy-eight RFI cases were tested. They may be categorized into three different sets:

(1) Telemetry data power variant: The CW signal was placed 1.2 Hz away from the upper telemetry subcarrier. The telemetry data rate was set at 2000 bps. The telemetry data power was set to three different levels; for each data power level, the telemetry data SNR degradation was measured at selected CW signal levels.

(2) Telemetry data rate variant: The CW signal was placed 1.2 Hz away from the upper telemetry subcarrier. The telemetry data was set to four different data rates; for each telemetry data rate, the telemetry data SNR degradation was measured at selected CW signal levels.

(3) CW interfering signal's effect on high-order (through the 27th) telemetry subcarrier harmonics: The telemetry signal level and data rate were fixed at −140.9 dBm and 2000 bps, respectively. The CW signal was placed coincident with each of the telemetry subcarrier harmonics one through twenty-seven (odd numbered harmonic only); for each case, the telemetry data SNR degradation was measured.

Tables 2 through 4 summarize the test cases performed.

# III. Bit Signal-to-Noise Ratio Degradation Analysis

## A. Summary of Previous Bit SNR Degradation Model

In a previous report (Ref. 1), a telemetry bit SNR degradation model for a fixed data rate of 2000 bps and a fixed telemetry data power of −140.5 dBm (composite average) in the presence of a CW interfering signal was presented. In developing the model, the CW interfering signal was treated as an extraneous noise. Using the basic definition of received bit SNR:

$$SNR_I = 10 \log \left(\frac{P_D T_B}{KT_S}\right)$$

and

$$SNR_{IR} = 10 \log \left[\frac{P_D T_B}{K(T_S + T_R)}\right]$$

where:

$SNR_I$ = received bit SNR when RFI is not present

$SNR_{IR}$ = received bit SNR when RFI is present

$P_D$ = total high-rate data power

$T_B$ = bit (symbol) time ($1/BR$)

$K$ = Boltzmann's constant

$T_S$ = effective system noise temperature when RFI is not present

$T_R$ = increased system noise temperature induced by the CW interfering signal.

Then, defining the received bit SNR degradation as:

$$\Delta SNR_I = SNR_I - SNR_{IR}$$

The mathematical expression of $\Delta SNR_I$ was derived:

$$\Delta SNR_I = 10 \log \left(\frac{T_S + T_R}{T_S}\right) \tag{1}$$

Also, using the basic relationships: (See Fig. 2)

$$SNR_O = SNR_I - L_S$$

and

$$SNR_{OR} = SNR_{IR} - L_{SR}$$

where:

$SNR_O$ = SSA bit SNR when RFI is not present

$SNR_{OR}$ = SSA bit SNR when RFI is present

$L_S$ = System loss when RFI is not present

$L_{SR}$ = System loss when RFI is present

And, defining the SSA bit SNR degradation as:

$$\Delta SNR_O = SNR_O - SNR_{OR}$$

the mathematical function of $\Delta SNR_O$ was expressed as:

$$\Delta SNR_O = \Delta SNR_I - (L_S - L_{SR}) \qquad (2)$$

Having Eqs. (1) and (2) established, the functional relationship of the CW interfering signal and the increased system noise temperature it induces for the case of the CW signal coincident with the telemetry subcarrier was empirically derived from the test data ($\Delta SNR_O$). The result was (NOTE: $L_S$ and $L_{SR}$ were obtained from the Telemetry Analysis Program):

$$T_R \Big|_{\substack{\Delta f_{1sc} = 0 \\ BR = 2K \\ P_D = -140.5 \text{ dBm}}} = \left[ \left(10^{8.21 e^{.0421 P_{RFI}}}\right)^2 + (40)^2 \right]^{1/2} - 39.5 \qquad (3)$$

where:

$\Delta f_{1sc}$ = frequency separation between the CW interfering signal and the telemetry subcarrier

$P_{RFI}$ = CW interfering signal level (dBm)

Then, the telemetry bit SNR degradation characteristic with the CW interfering signal at various frequency offsets from the subcarrier or subcarrier harmonics (test data included up to the fifth subcarrier harmonic) was investigated. This was done, first, by deriving the telemetry system's magnitude response function, which is:

$$|H(n, \Delta f_{nsc})|^2 = \left(\frac{h T_B}{n}\right)^2 \left(\frac{\sin(\pi \Delta f_{nsc} T_B)}{\pi \Delta f_{nsc} T_B}\right)^2$$

where:

$h$ = gain

$n$ = subcarrier harmonic number, $n$ = 1, 3, 5, etc

$$\Delta f_{nsc} = \begin{cases} |(f_c + f_{nsc}) - f_{RFI}| & \text{if } f_{RFI} > f_c \\ |(f_c - f_{nsc}) - f_{RFI}| & \text{if } f_{RFI} < f_c \end{cases}$$

$f_{nsc}$ = $nth$ harmonic of subcarrier ($n \cdot f_{sc1}$) ($1st$ harmonic is also referred to as subcarrier)

$f_{RFI}$ = CW interfering signal frequency.

Thus, the power response function of the telemetry system for any CW signal with power, $P$, would be:

$$P(n, \Delta f_{nsc}) = (P) \left(\frac{h T_B}{n}\right)^2 \left(\frac{\sin(\pi \Delta f_{nsc} T_B)}{\pi \Delta f_{nsc} T_B}\right)^2 \qquad (4)$$

Next, the following relationship (ratio) was formed:

$$\frac{P(n, \Delta f_{nsc})}{P(1, 0)} \Bigg|_{BR = 2K} = \left(\frac{1}{n^2}\right) \cdot \left(\frac{\sin(\pi \Delta f_{nsc} T_B)}{\pi \Delta f_{nsc} T_B}\right)^2$$

Expressing it in decibel format, and rearranging terms:

$$P(n, \Delta f_{nsc}) = P(1, 0) - 20 \log(n) + 10 \log \left(\frac{\sin(\pi \Delta f_{nsc} T_B)}{\pi \Delta f_{nsc} T_B}\right)^2$$

Finally, this relationship was integrated into Eq. (3) along with two adjustment factors (based on test data) to form a generalized expression for $T_R$:

$$T_R \Big|_{\substack{BR = 2K, \\ P_D = -140.5 \text{ dBm}}} = \left[ \left(10^{8.21 e^{0.0421 P_I}}\right)^2 + (40)^2 \right]^{1/2} - 39.5 \qquad (5)$$

$$P_I = P_{RFI} - (0.94) \cdot (20 \log n) + (0.90) \cdot \left[ 10 \log \left( \frac{\sin\left(\Delta f_{nsc} \left(\frac{\pi}{BR}\right)\right)}{\Delta f_{nsc} \left(\frac{\pi}{BR}\right)} \right)^2 \right] \qquad (6)$$

where

$BR = 1/T_B$

$n$ = number of the subcarrier harmonic which the CW interfering signal is affecting.

Thus, Eqs. (6), (5), (1), and (2) formed the telemetry bit SNR degradation model as presented in Ref. 1.

## B. Degradation as a Function of Telemetry Bit Rate and Telemetry Data Power

In this paragraph, the telemetry bit SNR degradation model as described in the preceding paragraph is to be generalized to include the telemetry bit rate and the telemetry data power as independent variables. To do this, an empirical approach is used. The functional relationship of the telemetry bit SNR degradation and the two telemetry parameters (bit rate and data power) in the presence of the CW interfering signal is derived from the test data.

Let us first assume that the effect of the CW interfering signal on the telemetry bit SNR is dependent on the telemetry bit rate and the telemetry data power. Let us further assume that for a CW interfering signal with power, $P$, input into the telemetry system, its relative effect on the telemetry bit SNR as a function of the telemetry bit rate and the telemetry data power may be expressed in terms of effective CW interfering signal power in the form of:

$$P_e = P \cdot \frac{(BR)^u}{(P_D)^v}$$

where:

$P_e$ = effective CW interfering signal power

$u, v$ = coefficients to be determined from the test data.

Substituting the above relationship into the telemetry system's power response function (Eq. 4), an effective power response function of the telemetry system for any CW signal with power $P$ is obtained:

$$P_e(P_D, BR, n, \Delta f_{nsc}) = P \cdot \frac{(BR)^u}{(P_D)^v}\left(\frac{h}{n \cdot BR}\right)^2 \left[\frac{\sin\left(\pi \frac{\Delta f_{nsc}}{BR}\right)}{\pi \frac{\Delta f_{nsc}}{BR}}\right]^2$$

Combining the $BR$ terms, and expressing the result in decibel format,

$$P_e(P_D, BR, n, \Delta f_{nsc}) = P - v(P_D) + 20\log(h) - 20\log(n)$$

$$- w(10\log BR)$$

$$+ 10\log\left[\frac{\sin\left(\pi \frac{\Delta f_{nsc}}{BR}\right)}{\pi \frac{\Delta f_{nsc}}{BR}}\right]^2$$

where $w = 2 - u$, the coefficient to be determined from the test data. Let $P_D = -140.5$ dBm, $BR = 2000$, $n = 1$, and $\Delta f_{nsc} = 0$. Then,

$$P_e(-140.5, 2000, 1, 0) = P - v(-140.5)$$

$$+ 20\log h - w(10\log 2000)$$

Thus (in decibel format),

$$P_e(P_D, BR, n, \Delta f_{nsc}) - P_e(-140.5, 2000, 1, 0) =$$

$$-v(P_D) + v(-140.5) - 20\log n$$

$$-w(10\log BR) + w(10\log 2000)$$

$$+ 10\log\left[\frac{\sin\left(\pi \frac{\Delta f_{nsc}}{BR}\right)}{\pi \frac{\Delta f_{nsc}}{BR}}\right]^2$$

Or,

$$P_e(P_D, BR, n, \Delta f_{nsc}) = P_e(-140.5, 2000, 1, 0) - v(P_D)$$

$$+ v(-140.5) - 20\log n$$

$$- w(10\log BR) + w(10\log 2000)$$

$$+ 10\log\left[\frac{\sin\left(\pi \frac{\Delta f_{nsc}}{BR}\right)}{\pi \frac{\Delta f_{nsc}}{BR}}\right]^2$$

Remember that Eq. (3) as described in the preceding paragraph is based on the telemetry bit rate of 2000 bps, telemetry data power of −140.5 dBm, and the interfering signal level $P_{RFI}$ with $\Delta f_{1sc}$ equal to zero. Thus, applying the above relationship, Eq. (3) may be generalized as:

$$T_R = \left[\left(10^{8.21 e^{0.0421 P_I}}\right)^2 + (40)^2\right]^{1/2} - 39.5 \qquad (7)$$

$$P_I = P_{RFI} - 20 \log n - r\,(P_D) + r\,(-140.5) - w\,(10 \log BR)$$

$$+ w\,(10 \log 2000) + 10 \log \left[\frac{\sin\left(\pi \dfrac{\Delta f_{nsc}}{BR}\right)}{\pi \dfrac{\Delta f_{nsc}}{BR}}\right]^2$$

From the test data, r and w are best determined to be 0.11 and 0.89, respectively. This, however, is done with the retention of the two adjustment factors (0.94 and 0.90), which were introduced into Eq. (6). Thus, $P_I$ becomes:

$$P_I = P_{RFI} - (0.94)(20 \log n) - (0.11)(P_D) + (0.11)(-140.5)$$

$$- (0.89)(10 \log BR) + (0.89)(10 \log 2000)$$

$$+ (0.90)\left[10 \log \left(\frac{\sin\left(\pi \dfrac{\Delta f_{nsc}}{BR}\right)}{\pi \dfrac{\Delta f_{nsc}}{BR}}\right)^2\right]$$

Simplifying the above equation, then:

$$P_I = P_{RFI} - (0.94)(20 \log n) - (0.11)\,P_D$$

$$- (0.89)(10 \log BR)$$

$$+ (0.90)\left[10 \log \left(\frac{\sin\left(\pi \dfrac{\Delta f_{nsc}}{BR}\right)}{\pi \dfrac{\Delta f_{nsc}}{BR}}\right)^2\right]$$

$$+ (13.924) \qquad (8)$$

Eqs. (7) and (8) may be further simplified by letting

$$P_R = P_I - (13.924)$$

Substituting this relationship into Eqs. (7) and (8), and then simplifying, the telemetry bit SNR degradation becomes:

$$P_R = P_{RFI} - (0.94)(20 \log n) - (0.11)\,P_D$$

$$- (0.89)(10 \log BR)$$

$$+ (0.90)\left[10 \log \left(\frac{\sin\left(\pi \dfrac{\Delta f_{nsc}}{BR}\right)}{\pi \dfrac{\Delta f_{nsc}}{BR}}\right)^2\right] \qquad (9)$$

$$T_R = \left(10^{2.951 e^{0.0421 P_R}} + 1600\right)^{1/2} - 39.5 \qquad (10)$$

$$\Delta SNR_I = 10 \log \left(\frac{T_S + T_R}{T_S}\right) \qquad (11)$$

$$\Delta SNR_O = \Delta SNR_I - (L_S - L_{SR}) \qquad (12)$$

Using this generalized model (Eqs. (9), (10), (11), and (12)), $\Delta SNR_I$ are calculated and plotted against the test data for test cases 1 through 64 in Figs. 3 and 4.

## C. Interfering Signal's Effect on High-Order Telemetry Subcarrier Harmonics

The CW interfering signal's effect on telemetry bit SNR when the CW interfering signal is placed at various high-order subcarrier harmonics is to be investigated in this paragraph. To do this, let us first examine the band-pass characteristic of the telemetry channel of the receiver system used for the test.

The receiver system used for the test is a double-heterodyne phase-locked receiver system. The simplified functional block diagram of the telemetry channel of the receiver system is shown in Fig. 5. As can be seen in Fig. 5, the desired carrier input to the receiver system is being down-converted in two stages to a 10-MHz IF signal, which is then fed into the Subcarrier Demodulator Assembly for carrier and subcarrier demodulation. The overall normalized magnitude response of this 10-MHz IF telemetry channel of the receiver system is shown in Fig. 6. Thus, the CW interfering signal (or any extraneous signal) that passes through the receiver is subjected to (1) the frequency down-conversion as is the desired carrier, and (2) the corresponding signal level attenuation as characterized by the normalized magnitude response (Fig. 6). Therefore, in evaluating the CW interfering signal's effect on the telemetry bit SNR when the CW interfering signal is at a high-order subcarrier harmonic (or at any frequency away from the carrier), the CW signal level, $P_{RFI}$, in Eq. (9) must be accounted for its attenuation due to the receiver's magnitude response as shown in Fig. 6. Using Fig. 6 and the telemetry bit SNR degradation model derived in the preceding paragraph, $\Delta SNR_I$ are calculated and tabulated against the test data for the test cases 65 through 78 in Table 5.

The receiver's normalized magnitude response curve, as shown in Fig. 6, represents the nominal design characteristics; the actual normalized magnitude response is not presently available. Because of this and the fact that the nominal design normalized magnitude response curve, as shown in Fig. 6, covers only a relatively small frequency domain (about 9 MHz), the receiver's normalized magnitude response function is not presented in this report.

## IV. Summary of Analysis Results

When a CW interfering signal is present in the DSS tracking and telemetry data processing system, the telemetry bit SNR is degraded. The telemetry bit SNR degradation as a function of the CW interfering signal power, the frequency separation between the CW interfering signal and the desired telemetry subcarrier, and the effective system noise temperature of the DSS tracking and telemetry data processing system was modeled in the previous report (Ref. 1). In this report, the telemetry bit SNR degradation was found to be also dependent on the telemetry bit rate and the telemetry data power. The bit SNR degradation model was generalized to include all these variables:

$$\Delta SNR_O = \Delta SNR_I - (L_S - L_{SR})$$

$$\Delta SNR_I = 10 \log \left( \frac{T_S + T_R}{T_S} \right)$$

where

$$T_R = \left( 10^{2.951 e^{0.0421 P_R}} + 1600 \right)^{1/2} - 39.5$$

$$P_R = P_{RFI} - (0.94)(20 \log m) - (0.11) P_D - (0.89)(10 \log BR) + (0.90) \left[ 10 \log \left( \frac{\sin \left( \pi \frac{\Delta f_{nsc}}{BR} \right)}{\pi \frac{\Delta f_{nsc}}{BR}} \right)^2 \right]$$

When the CW interfering signal is significantly away from (or not coincident with) the desired carrier in frequency, the effective CW interfering signal power is reduced. The reduction is due to the relative attenuation caused by the receiver's normalized magnitude response as shown in Fig. 6. Therefore, in calculating the bit SNR degradation, the $P_{RFI}$ term in the above bit SNR degradation model must be adjusted for its signal level reduction with the corresponding attenuation caused by the receiver's normalized magnitude response. The receiver's normalized magnitude response function was not included in this analysis because of the lack of actual data.

## V. Conclusions

Based on the test data obtained from this series of CW interference tests, the telemetry bit SNR degradation model previously developed (Ref. 1) was generalized to include the telemetry data rate and the telemetry data power as independent variables. Test results showed that the telemetry bit SNR degradation is relatively more sensitive to the telemetry data rate than the telemetry data power. The test results of the CW interference effect on the high-order telemetry subcarrier harmonics revealed that when the CW interfering signal is away from the desired carrier in frequency, the effective interfering power is reduced due to the receiver's band-pass characteristics (magnitude response). Thus, when using the telemetry bit SNR degradation model, the CW interfering signal power must be adjusted (reduced) accordingly with the receiver's band-pass characteristic function. Because of the lack of actual data, the receiver's band-pass characteristic function was not derived in this analysis.

Additional tests and analysis are needed to better understand the DSS equipment's RFI susceptibility. Some major tasks will include:

(1) The receiver's band-pass characteristic function and its image rejection capability.

(2) Effects on the telemetry system for various kinds of interference spectrum.

## Reference

1. Low, P. W., "Radio Frequency Interference Effects of Continuous Sinewave Signals on Telemetry Data" in *The Deep Space Network Progress Report 42-40*, Jet Propulsion Laboratory, Pasadena, Calif., August 15, 1977.

### Table 1. Desired downlink signal configuration

| | |
|---|---|
| Carrier frequency ($f_c$) | 2293.148160 MHz |
| Carrier power ($P_c$) | See Tables 2–4 |
| **High rate data** | |
| Subcarrier frequency ($f_{sc1}$) | 240 kHz |
| Data format | Uncoded |
| Bit rate ($BR$) | See Tables 2–4 |
| Modulation index | 66.54 degrees |
| Data power ($P_D$) | See Tables 2–4 |
| **Low rate data** | |
| Subcarrier frequency | 24 kHz |
| Data format | Uncoded |
| Bit rate | 33-1/3 bps |
| Modulation index | 19.25 degrees |
| Data power | ($P_c$ − 9.11) dBm |

### Table 2. Telemetry data power variant test cases

| Test number | $P_c$, dBm | $P_D$, dBm | $BR$, bps | $T_S$, K | $P_{REF}$, dBm | $f_{REF}$, Hz |
|---|---|---|---|---|---|---|
| 1 | −141.5 | −134.3 | 2000 | 25.2 | −165.5 | $f_c + f_{sc1} + 1.2$ |
| 2 | | | | | −160.0 | |
| 3 | | | | | −155.0 | |
| 4 | | | | | −150.0 | |
| 5 | | | | | −146.0 | |
| 6 | | | | | −143.0 | |
| 7 | | | | | −140.0 | |
| 8 | | | | | −137.0 | |
| 9 | ▼ | ▼ | | | −134.5 | |
| 10 | −141.5 | −134.3 | | | −132.0 | |
| 11 | −148.1 | −140.9 | | | −154.5 | |
| 12 | | | | | −149.5 | |
| 13 | | | | | −145.0 | |
| 14 | ▼ | ▼ | | | −142.5 | |
| 15 | −148.1 | −140.9 | | | −140.0 | |
| 16 | −155.0 | −147.8 | | | −165.0 | |
| 17 | | | | | −160.0 | |
| 18 | | | | | −155.0 | |
| 19 | | | | | −151.0 | |
| 20 | ▼ | ▼ | ▼ | ▼ | −148.0 | ▼ |
| 21 | −155.0 | −147.8 | 2000 | 25.2 | −146.0 | $f_c + f_{sc1} + 1.2$ |

Table 3. Telemetry data rate variant test cases

| Test number | $P_c$, dBm | $P_D$, dBm | $BR$, bps | $T_S$, K | $P_{RFI}$, dBm | $f_{RFI}$, Hz |
|---|---|---|---|---|---|---|
| 22 | -157.5 | -150.3 | 200 | 25.2 | -165.0 | $f_c + f_{sc1} + 1.2$ |
| 23 | | | | | -160.5 | |
| 24 | | | | | -155.0 | |
| 25 | | | | | -152.0 | |
| 26 | -157.5 | -150.3 | 200 | 25.2 | -151.0 | |
| 27 | -145.0 | -137.8 | 4,000 | 25.6 | -164.0 | |
| 28 | | | | | -160.0 | |
| 29 | | | | | -157.0 | |
| 30 | | | | | -154.0 | |
| 31 | | | | | -151.0 | |
| 32 | | | | | -148.0 | |
| 33 | | | | | -145.0 | |
| 34 | | | | | -142.5 | |
| 35 | | | | | -139.5 | |
| 36 | | | | | -137.5 | |
| 37 | -145.0 | -137.8 | 4,000 | | -135.0 | |
| 38 | -138.0 | -130.8 | 20,000 | | -164.0 | |
| 39 | | | | | -160.0 | |
| 40 | | | | | -157.0 | |
| 41 | | | | | -154.0 | |
| 42 | | | | | -151.0 | |
| 43 | | | | | -148.0 | |
| 44 | | | | | -145.0 | |
| 45 | | | | | -142.0 | |
| 46 | | | | | -139.0 | |
| 47 | | | | | -137.0 | |
| 48 | | | | | -135.0 | |
| 49 | | | | | -133.5 | |
| 50 | | | | | -131.5 | |
| 51 | | | | | -129.5 | |
| 52 | -138.0 | -130.8 | 20,000 | 25.6 | -127.5 | |
| 53 | -130.5 | -123.3 | 80,000 | 25.2 | -165.0 | |
| 54 | | | | | -160.0 | |
| 55 | | | | | -155.0 | |
| 56 | | | | | -150.0 | |
| 57 | | | | | -146.0 | |
| 58 | | | | | -143.0 | |
| 59 | | | | | -140.0 | |
| 60 | | | | | -136.5 | |
| 61 | | | | | -134.0 | |
| 62 | | | | | -131.5 | |
| 63 | | | | | -128.0 | |
| 64 | -130.5 | -123.3 | 80,000 | 25.2 | -125.0 | $f_c + f_{sc1} + 1.2$ |

**Table 4. Test cases of CW interfering signal coincident with various telemetry subcarrier harmonics**

| Test number | $P_c$, dBm | $P_D$, dBm | $BR$, bps | $T_S$, K | $P_{RFI}$, dBm | $f_{RFI}$, Hz |
|---|---|---|---|---|---|---|
| 65 | −148.1 | −140.9 | 2,000 | 25.2 | −140.0 | $f_c + f_{sc1}$ |
| 66 | | | | | −140.0 | $f_c + 3xf_{sc1}$ |
| 67 | | | | | −140.0 | $f_c + 5xf_{sc1}$ |
| 68 | | | | | −128.0 | $f_c + 7xf_{sc1}$ |
| 69 | | | | | −128.0 | $f_c + 9xf_{sc1}$ |
| 70 | | | | | −128.0 | $f_c + 11xf_{sc1}$ |
| 71 | | | | | −121.0 | $f_c + 13xf_{sc1}$ |
| 72 | | | | | −121.0 | $f_c + 15xf_{sc1}$ |
| 73 | | | | | −121.0 | $f_c + 17xf_{sc1}$ |
| 74 | | | | | −121.0 | $f_c + 19xf_{sc1}$ |
| 75 | | | | | −121.0 | $f_c + 21xf_{sc1}$ |
| 76 | | | | | −121.0 | $f_c + 23xf_{sc1}$ |
| 77 | | | | | −121.0 | $f_c + 25xf_{sc1}$ |
| 78 | −148.1 | −140.9 | 2,000 | 25.2 | −121.0 | $f_c + 27xf_{sc1}$ |

**Table 5. $\Delta SNR_I$ vs $P_{RFI}$ for CW interfering signal coincident with various telemetry subcarrier harmonics**

| Subcarrier harmonic | $P_{RFI}$, dBm | CW interfering signal attenuation (Fig. 6) (dB) | Measured $\Delta SNR_I$, dB | Calculated $\Delta SNR_I$, dB |
|---|---|---|---|---|
| 1 | −140 | 0 | 8.63 | 8.41 |
| 3 | −140 | 0.2 | 2.34 | 1.86 |
| 5 | −140 | 0.4 | 0.75 | 0.76 |
| 7 | −128 | 0.8 | 4.08 | 4.34 |
| 9 | −128 | 1.4 | 1.96 | 2.68 |
| 11 | −128 | 2.3 | 1.63 | 1.61 |
| 13 | −121 | 3.2 | 3.97 | 4.02 |
| 15 | −121 | 4.1 | 3.60 | 2.75 |
| 17 | −121 | 5.1 | 2.05 | 1.84 |
| 19 | −121 | 6.1 | 1.92 | 1.24 |
| 21 | −121 | 7.3 | 1.26 | 0.82 |
| 23 | −121 | 8.4 | 0.82 | 0.58 |
| 25 | −121 | 9.6 | 0.42 | 0.42 |
| 27 | −121 | 11.0 | 0.20 | 0.31 |

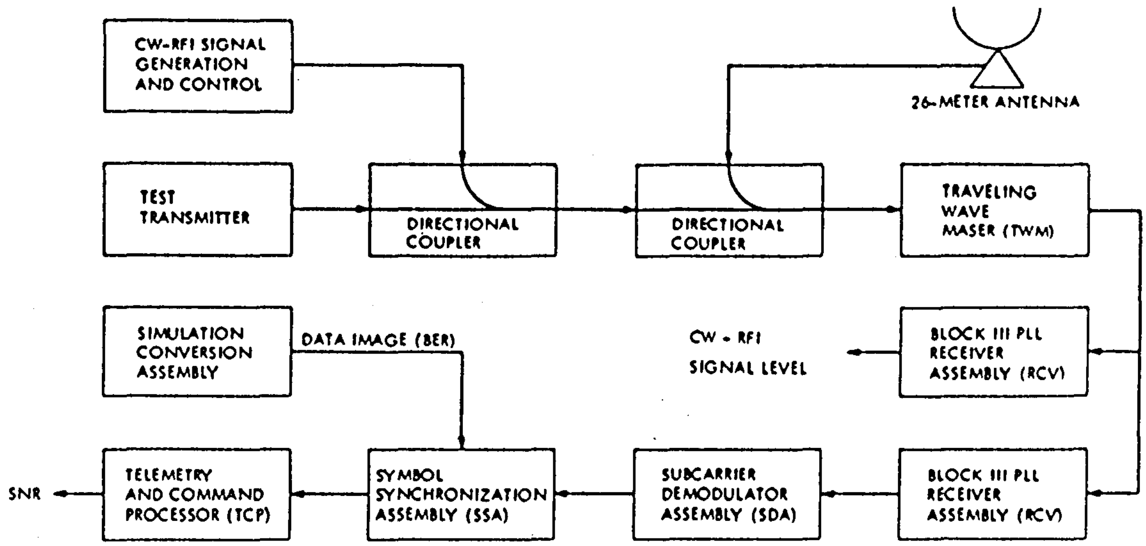


**Fig. 1. Test configuration**

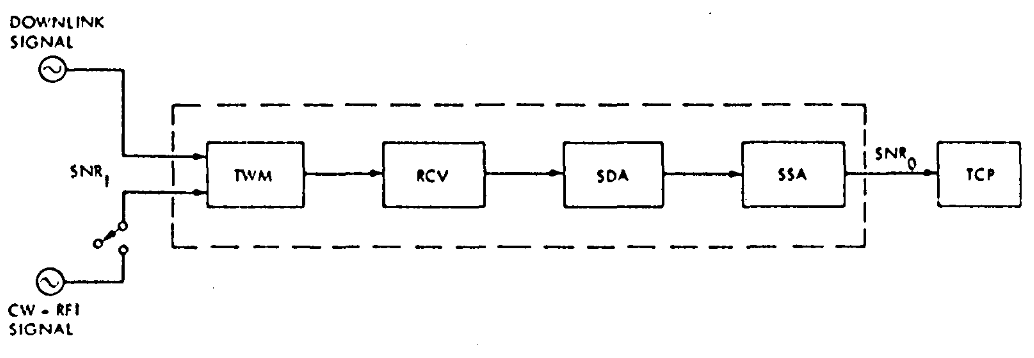


**Fig. 2. Simplified carrier tracking and telemetry processing system**

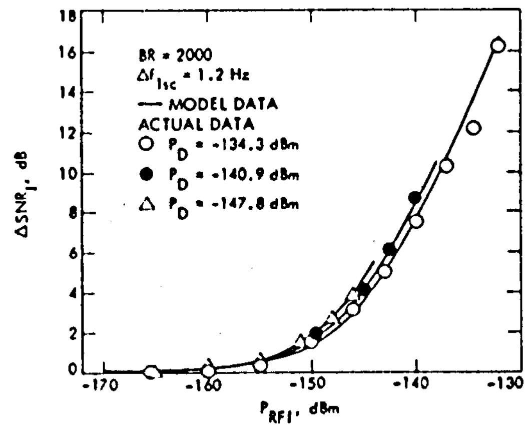


Fig. 3. $\Delta\ SNR_I$ vs $P_{RFI}$ for selected values of $P_D$

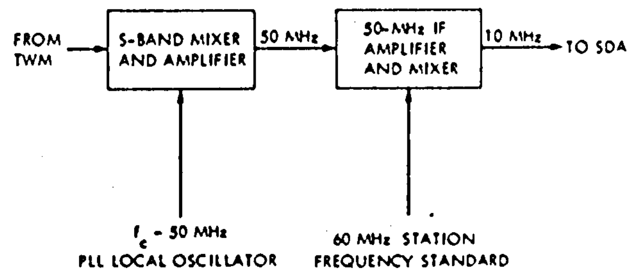


Fig. 5. Block III receiver telemetry function simplified block diagram

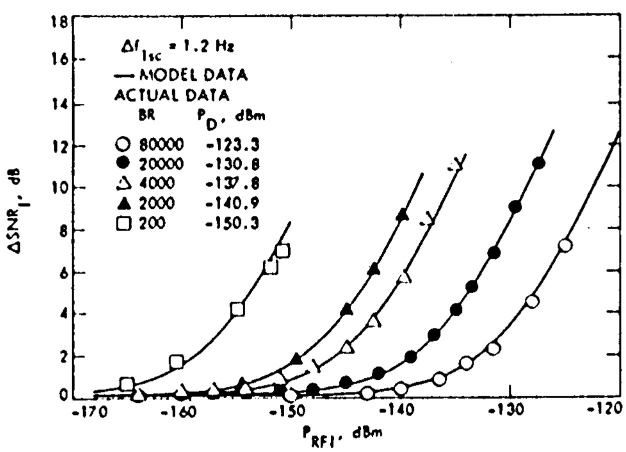


Fig. 4. $\Delta\ SNR_I$ vs $P_{RFI}$ for selected values of $BR$

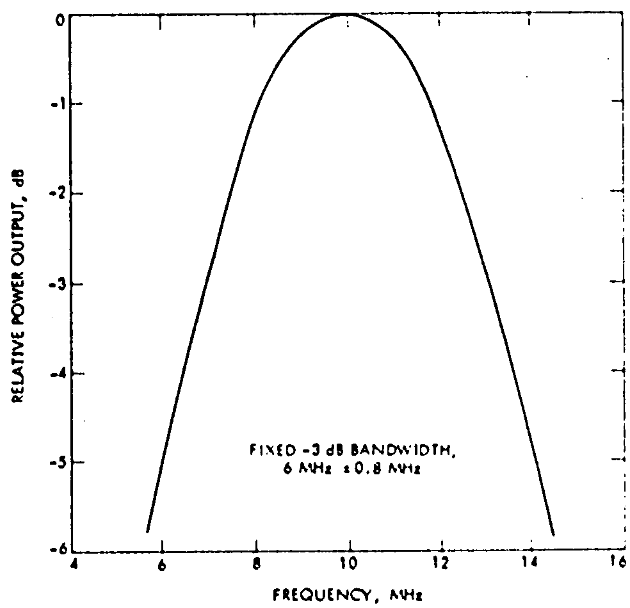


Fig. 6. Block III receiver 10-MHz telemetry output magnitude response characteristics